

1. $X_1, X_2, \dots, X_n$ are independent $N(\mu, \sigma^2)$ variables. Determine the distributions of $\sum_{i=1}^n X_i$, $\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i$, $\sqrt{n} \left(\frac{\bar{X} - \mu}{\sigma} \right)$, $n \left(\frac{\bar{X} - \mu}{\sigma} \right)^2$, $\frac{X_i - \mu}{\sigma}$, $\left(\frac{X_i - \mu}{\sigma} \right)^2$ and $\sum_{i=1}^n \left(\frac{X_i - \mu}{\sigma} \right)^2$.
2. If $X_1, X_2, \dots, X_{25}$ are independent $N(1, 4)$ variables, calculate $P \left(\sum_{i=1}^{25} X_i > 30 \right)$, $P(\bar{X} < 0)$ and find k_1 and k_2 such that $P(\bar{X} < k_1) = 0.3$ and $P \left(\frac{\bar{X} - 1}{S} < k_2 \right) = 0.99$, where $\bar{X}$ and S^2 are the sample mean and variance.
3. Verify that about 2/3 of the values of normal random variables lie within one standard deviation of the mean and about 95 percent within 2 standard deviations of the mean.
4. For a normal distribution with mean 30 and variance 16, show that about 494 observations in a random sample of 500 would be between 20 and 40.
5. A soft drink machine delivers tumblers of drink with mean content 200 mls and a standard deviation of 15 mls. If a random sample of 36 tumblers is taken, what is the probability that the mean content for the sample is at least 204 mls?
6. Find the probability that the sum of 9 independent $N(0, 1)$ variables exceeds 1.
7. Find from tables $P(\chi_6^2 > 7.23)$, $P(\chi_{11}^2 < 3.05)$, $P(\chi_{17}^2 < 21.62)$, $P(\chi_4^2 > 0.484)$ and k such that $P(\chi_{15}^2 < k) = 0.95$.
8. With independent standard normal variables U_i ,
 - a) find the value k such that $\sum_{i=1}^6 U_i^2$ exceeds k 5% of the time,
 - b) calculate, as accurately as tables permit, the probability that $\sum_{i=1}^6 U_i^2$ exceeds 3.
9. If $X_1, X_2, \dots, X_{10}$ constitute a random sample from a $N(2, 25)$ distribution, find the values α and β such that with probabilities 0.01 $\frac{1}{10} \sum_{i=1}^{10} (X_i - 2)^2 > \alpha$ and $\frac{1}{9} \sum_{i=1}^{10} (X_i - \bar{X})^2 > \beta$.

Answers

1. $N(n\mu, n\sigma^2)$, $N(\mu, \frac{\sigma^2}{n})$, $N(0, 1)$, χ_1^2 , $N(0, 1)$, χ_1^2 , χ_n^2 .
2. $k_1 = -0.31$, $k_2 = 0.498$.
5. 0.0548.
6. 0.3707.
7. 0.3, 0.01, 0.8, 0.975, $k = 25$.
8. $k = 12.59$, 0.8+.
9. $\alpha = 58$, $\beta = 60$.

DEPARTMENT OF STATISTICS

MATH2801 Theory of Statistics

Tutorial Problems Week 2

Session 1, 2003

1. Suppose A, B and C represent three events. Using unions, intersections and complements, find expressions representing the events
 - a) only A occurs,
 - b) all three events occur,
 - c) at least one event occurs,
 - d) exactly one event occurs,
 - e) exactly two events occur,
2. Tom and Bob play a game by each tossing a fair coin. The game consists of tossing the two coins together, until for the first time either two heads appear when Tom wins, or two tails appear when Bob wins. Show that the probability that
 - a) Tom wins at or before the n th toss is $\frac{1}{2} - \frac{1}{2^{n+1}}$,
 - b) the game is decided at or before n th toss is $1 - \frac{1}{2^n}$.
3. Urn 1 contains 2 red balls and 3 black balls. Urn 2 contains 4 red balls and 5 black balls.
 - a) If an urn is randomly selected and a ball drawn at random from it, what is the probability that the ball is red?
 - b) Suppose a ball is drawn at random from urn 1 and placed into urn 2. If a ball is then drawn at random from the 10 balls in urn 2, what is the probability that it is red?
 - c) In part b), given that the ball drawn from urn 2 is red, what is the probability that the ball transferred from urn 1 was black?
4. 10% of all electronic components of a particular type become defective in their first year of operation. Of those which survive 1 year, 20% become defective in the next year and, of those which last at least 2 years, 50% become defective in their third year.
 - a) Find the probability that a component will last at least 2 years.
 - b) Calculate the percentage of components which break down within 3 years.
 - c) Find the probability that a component will last at least 3 years, given that it lasts at least 1 year.
5. A certain rare disease afflicts 1 person in 1,000. A new diagnostic test for the disease is 98% efficient in the sense that in 98% of tests the result is positive when a person has the disease and the result is negative in 98% of cases when the person does not have the disease. Calculate the probability that a randomly chosen person

- a) tests negative and has the disease,
- b) tests negative,
- c) has the disease, given that the person tests negative.

Answers

1. $A \cap \bar{B} \cap \bar{C}$, $A \cap B \cap C$, $A \cup B \cup C$, $(A \cap \bar{B} \cap \bar{C}) \cup (\bar{A} \cap B \cap \bar{C}) \cup (\bar{A} \cap \bar{B} \cap C)$,
 $(A \cap B \cap \bar{C}) \cup (A \cap \bar{B} \cap C) \cup (\bar{A} \cap B \cap C)$.
3. 19/45 , 11/25 , 6/11.
4. 0.72 , 0.64 , 0.4.
5. 0.00002 , 0.97904 , 1/48952.

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MATH2801 Theory of Statistics

Tutorial Problems Week 6

Session 1, 2003

1. Random variables X and Y have joint density

$$f_{X,Y}(x,y) = 2xy, \quad 0 < x < 2y, \quad 0 < y < 1.$$

- a) Show that X has density

$$f_X(x) = x \left(1 - \frac{x^2}{4}\right), \quad 0 < x < 2.$$

- b) Calculate $E(Y|X = 1)$.

- c) Find the density of $Z = \frac{X}{2}$.

2. For any random variables X and Y , $E(Y|X)$ is defined to be $a(X)$, where $a(x) = E(Y|X = x)$. Prove that $E\{E(Y|X)\} = E(Y)$.

3. Find the density of $Y = X^2$ when $X \sim \text{Uniform}(0,1)$.

4. Suppose X and Y are independent with $X \sim \text{Poisson}(\lambda)$, $Y \sim \text{Poisson}(\lambda)$. Show that $X + Y \sim \text{Poisson}(2\lambda)$ using

- a) the convolution formula
b) moment generating functions.

5. If $X \sim N(\mu, \sigma^2)$ show that $Y = \frac{X-\mu}{\sigma} \sim N(0,1)$ using

- a) the transformation formula,
b) moment generating functions.

6. Use moment generating functions to find the distribution of $aX + bY$, where X and Y are independent, $X \sim N(\mu, \sigma^2)$, $Y \sim N(\mu, \sigma^2)$ and a, b are constants.

Answers

1. b) $7/9$
c) $f_Z(z) = 4z(1 - z^2), 0 < z < 1$.
3. $f_Y(y) = \frac{1}{2\sqrt{y}}, 0 < y < 1$.
6. $aX + bY \sim N((a+b)\mu, (a^2 + b^2)\sigma^2)$.

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MATH2801 Theory of Statistics

Tutorial Problems Week 5

Session 1, 2003

1. A random variable X has probability function

x	-2	-1	0	1
$P(X = x)$	1/4	1/8	1/2	1/8

- Calculate $P(X = 0|X < 1)$ and $P(X < 0|X < 1)$.
- Tabulate the probability function of $Y = X^2 + 1$.
- If X_1 and X_2 are independent and each with the same probability function as X above, find

$$P(X_1 X_2 = -1) \text{ and } P(X_1 + X_2 = 0).$$

2. Random variables X and Y have joint probability function

		Y		
		0	1	2
X	-1	.08	.16	.16
	1	.04	.06	.10
	2	.08	.18	.14

- Calculate the mean and variance of X .
 - Determine the probability function of the random variable $Z = X + Y$.
 - Find $P(X = 1|Y = 2)$ and $P(X \leq 1|Y \leq 1)$.
 - Are X and Y independent? Justify your answer.
3. A random variable X has density $f_X(x) = 2x, 0 < x < 1$.
- Calculate $P(X < \frac{1}{2}|X > \frac{1}{3})$.
 - Find the density of $Y = X^2$.
4. Random variables X and Y have joint density $f_{X,Y}(x,y) = 6x, 0 < x < y < 1$.
- Show that Y has density $f_Y(y) = 3y^2, 0 < y < 1$.
 - Prove that the conditional density of X given $Y = y$ is

$$f_{X|Y}(x|y) = \frac{2x}{y^2}, 0 < x < y.$$

- Calculate $P(X < \frac{1}{2}|Y = y)$ and $E(X|Y = y)$.

d) Calculate $P(X > \frac{1}{2}, Y > \frac{1}{2})$.

5. Find the probability function of $Z = X + Y$ when X and Y are independent and

$$P(X = k) = P(Y = k) = (1 - \omega)\omega^k, \quad k = 0, 1, 2, \dots; \quad 0 < \omega < 1.$$

Answers

1. a) $4/7, 3/7$

b)

y	1	2	5
$P(Y = y)$	$1/2$	$1/4$	$1/4$

c) $1/32$

2. a) $0.6, 1.84$

b)

z	-1	0	1	2	3	4
$P(Z = z)$	$.08$	$.16$	$.20$	$.14$	$.28$	$.14$

c) $1/4, 17/30$

d) No

3. a) $5/32$

b) $f_Y(y) = 1, 0 < y < 1.$

4. c) $1/4y^2, 2y/3.$

d) $1/2.$

5. $P(Z = n) = (n + 1)(1 - \omega)^2\omega^n, n = 0, 1, 2, \dots$

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MATH2801 Theory of Statistics

Tutorial Problems Week 4

Session 1, 2003

1. Find $E(1 + X)^{-1}$ when $X \sim \text{Poisson}(\lambda)$.
2. Show that, in general, $E(1/X) \neq 1/E(X)$ by considering X with density $f(x) = 1$, $1 < x < 2$.
3. Let X have density $f(x) = \alpha x^{-\alpha-1}$, $x > 1$; $\alpha > 0$.
 - a) Find $E(X)$.
 - b) For which values of α is $\text{Var}(X) < \infty$?
4. Find $E(X)$ and $\text{Var}(X)$ when $f(x) = 2x$, $0 < x < 1$.
5. A random square has a side length X which has the density $f(x) = 1$, $0 < x < 1$. Find the mean and variance of the area of the square.
6. A random circle has radius R which has density $f(r) = 1$, $0 < r < 1$. Find the mean of the circumference and the mean of the area inside the circle.
7. Random variables X and Y have joint probability function as follows:

		Y		
		-1	0	1
X	0	.01	.08	.01
	1	.05	.42	.03
	2	.04	.30	.06

- a) Calculate $E(X)$, $P(X = 1|Y = 1)$, $E(X|Y = 1)$ and $P(X + Y = 1)$.
 - b) Are X and Y independent?
8. Random variables X and Y have joint density

$$f_{X,Y}(x,y) = 8xy, \quad 0 < x < y < 1.$$

- a) Find $f_X(x)$ and $f_Y(y)$, the densities of X and Y .
- b) Calculate $P(X < \frac{1}{2}, Y < \frac{1}{2})$.
- c) Are X and Y independent?

Answers

1. $(1 - e^{-\lambda})/\lambda$.
3. a) $\alpha/1 - \alpha$ for $\alpha > 1, \infty$ for $\alpha \leq 1$,
b) $\alpha > 2$.
4. $2/3$, $1/18$.
5. $1/3$, $4/45$
6. π , $\pi/3$
7. 1.3 , 0.3 , 1.5 , 0.47
8. a) $f_X(x) = 4x(1 - x^2), 0 < x < 1$
 $f_Y(y) = 4y^3, 0 < y < 1$
b) $1/16$,
c) No.

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MATH2801 Theory of Statistics

Tutorial Problems Week 3

Session 1, 2003

1. Find $E(X)$ when

a) $P(X = x) = (1 - \omega)\omega^{x-1}$, $x = 1, 2, \dots$; $0 < \omega < 1$.

b) $P(X = x) = \binom{m}{x} \omega^x (1 - \omega)^{m-x}$, $x = 0, 1, \dots, m$; $0 < \omega < 1$.

2. Calculate $F(x) = P(X \leq x)$ and hence find the median of the distribution when X has density $f(x) = \theta e^{-\theta x}$, $x > 0$; $\theta > 0$. Find $E(X)$.

3. Calculate $E(X)$ and $\text{Var}(X)$ when

a) X has probability function

$$f(x) = P(X = x) = e^{-\lambda} \frac{\lambda^x}{x!}, \quad x = 0, 1, 2, \dots; \quad \lambda > 0,$$

b) X has density

$$f(x) = \theta x^{\theta-1}, \quad 0 < x < 1; \quad \theta > 0.$$

4. Suppose X has mean μ and variance σ^2 . Find expressions for the mean and variance of $aX + b$ in terms of μ and σ^2 when a and b are constants.

5. Determine $m(u) = E(e^{uX})$ when X had density $f(x) = 1$, $0 < x < 1$. Expand $m(u)$ in powers of u and hence find $E(X)$ and $\text{Var}(X)$.

Answers

1. a) $(1 - \omega)^{-1}$,

b) $m\omega$.

2. $x_{0.5} = \frac{1}{\theta} \ln 2$, $E(X) = \frac{1}{\theta}$.

3. a) λ, λ ,

b) $\frac{\theta}{\theta+1}$, $\frac{\theta}{(\theta+2)(\theta+1)^2}$.

4. $a\mu + b$, $a^2\sigma^2$.

5. $\frac{1}{2}$, $\frac{1}{12}$.

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DEPARTMENT OF STATISTICS

MATH2801 THEORY OF STATISTICS

Tutorial Problems - Week 10, 2003

1. Obtain the minimum variance bounds for unbiased estimators of θ based on random samples of size n from the densities $f(x; \theta) = (\theta + 1)x^\theta$, $0 < x < 1$; $\theta > -1$ and $f(x; \theta) = \theta/(1+x)^{\theta+1}$, $0 < x < \infty$; $\theta > 0$. Do the umvue's of θ have variances equal to the bounds?

2. Suppose $X_1, X_2, \dots, X_n$ are independent and each with the truncated Poisson probability function

$$f(x; \lambda) = (e^\lambda - 1)^{-1} \frac{\lambda^x}{x!}, \quad x = 1, 2, \dots; \quad \lambda > 0.$$

- a) Show that the mle of λ is the solution of $\lambda(1 - e^{-\lambda})^{-1} = \bar{X}$.
b) Find the minimum variance bound for unbiased estimators of λ .
c) Is there an unbiased estimator of λ with variance equal to the bound in b)?
d) Does the umvue of $e^{-\lambda}$ have variance equal to the lower bound for the variance of an unbiased estimator of $e^{-\lambda}$?
3. Obtain the minimum variance bounds for unbiased estimators of θ and $\ln(1 + \theta)$ based on a random sample of size n from the density $f(x; \theta) = (1 + \theta)(x + \theta)^{-2}$, $x \geq 1$; $\theta > -1$. Do the umvue's of θ and $\ln(1 + \theta)$ have variances equal to the corresponding bounds?

Answers

1. $(\theta + 1)^2/n$, θ^2/n , no.
2. $\lambda(e^\lambda - 1)^2/ne^\lambda(e^\lambda - \lambda - 1)$, no, no.
3. $3(1 + \theta)^2/n$, $3/n$, no.

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MATH2801 THEORY OF STATISTICS

Tutorial Problems - Week 11, 2003

1. The article 'The influence of Corrosion Inhibitor and Surface Abrasion on the Failure of Aluminium-Wired Twist-on Connections' (IEEE Trans. Components, Hybrids and Manuf. Tech., 1984, pp. 20-25) reported the following summary data on potential drop measurements for a sample of connectors wired with alloy aluminium and for another sample wired with EC aluminium:

Type	Sample Size	Sample Mean	Sample Standard Deviation
Alloy	21	17.5	0.55
EC	21	16.9	0.49

Assuming normality, calculate

- a) a 95% confidence interval for the mean potential drop for connectors wired with alloy aluminium,
 - b) a 99% confidence interval for the variance of the potential drop for connectors wired with alloy aluminium,
 - c) a 95% confidence interval for the difference of the means of potential drops, assuming common variance,
 - d) a 99% confidence interval for the ratio of the standard deviations of the potential drops.
2. If T is the largest of n independent Uniform $(0, \theta)$ random variables, then T has density $f_T(t) = \frac{nt^{n-1}}{\theta^n}$, $0 < t < \theta$.
 - a) Prove that $Z = \frac{T}{\theta}$ is a pivotal function and hence derive a $(1 - \alpha)$ -confidence interval for θ .
Hint: $f_Z(z) = f_T(t) \left| \frac{dt}{dz} \right|$.
 - b) Given that T is the maximum likelihood estimator of θ , derive a $(1 - \alpha)$ -confidence interval for θ based on T .

3. Suppose $X_1, X_2, \dots, X_n$ are independent random variables, each with density

$$f(x; \theta) = e^{-(x-\theta)}, \quad x \geq \theta; \quad -\infty < \theta < \infty.$$

$T = \min(X_1, X_2, \dots, X_n)$ is the maximum likelihood estimator of θ .

- a) Prove that T has cumulative distribution function

$$F_T(t; \theta) = P(T \leq t) = 1 - e^{-n(t-\theta)}, \quad t \geq \theta.$$

- b) Use a general method of constructing confidence intervals to derive a $(1 - \alpha)$ -confidence interval for θ based on T .

4. Suppose X is a single observation from the density

$$f(x; \theta) = \frac{2x}{\theta^2}, \quad 0 < x < \theta; \quad \theta > 0.$$

- a) Prove that $\frac{X}{\theta}$ is a pivotal function and hence derive a $(1 - \alpha)$ -confidence interval for θ .

- b) Given that X is the maximum likelihood estimator of θ , find a $(1 - \alpha)$ -confidence interval for θ based on X .

Answers

1. $(17.25, 17.75), (0.15, 0.81), (0.27, 0.93), (0.62, 2.04)$.
2. $\left(T \left(1 - \frac{\alpha}{2} \right)^{-1/n}, T \left(\frac{\alpha}{2} \right)^{-1/n} \right)$ for a) and b).
3. b) $\left(T + \frac{1}{n} \ln \left(\frac{\alpha}{2} \right), T + \frac{1}{n} \ln \left(1 - \frac{\alpha}{2} \right) \right)$.
4. $\left(X \left(1 - \frac{\alpha}{2} \right)^{-1/2}, X \left(\frac{\alpha}{2} \right)^{-1/2} \right)$ for a) and b).

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MATH2801 THEORY OF STATISTICS

Tutorial Problems - Week 12, 2003

1. The article 'The Acute Effects of Chrysotile Asbestos Exposure on Lung Function' in the 1978 issue of Environmental Research reports the values of the pulmonary compliance (in $\text{cm}^3/\text{cm H}_2\text{O}$) for 16 persons 8 months after a prolonged period of exposure to asbestos (pulmonary compliance is a measure of lung elasticity). The sample mean and sample standard deviation were 209.75 and 24.156. Assuming normality, calculate
 - a) a 95% confidence interval for mean pulmonary compliance,
 - b) a 99% confidence interval for the variance of pulmonary compliance.
2. Suppose $X_1, X_2, \dots, X_9$ are iid $N(\mu, 4)$ variables. We wish to test $H_0 : \mu = 1$ against $H_1 : \mu = 3$.
 - a) Calculate the size and power of the test with rejection region $\bar{x} > 2$.
 - b) Find k so that the test with rejection region $\bar{x} > k$ has size .05. Calculate the power of this test.
3. A coin is tossed 3 times. We wish to test $H_0 : \omega = \frac{1}{4}$ versus $H_1 : \omega = \frac{1}{2}$, where ω is the probability of a head on a single toss. Calculate the size and power of a test procedure which specifies that we reject H_0 if at least 2 heads turn up.
4. Let X be a sample of size 1 from the density

$$f(x; \theta) = \theta e^{-\theta x}, x > 0; \theta > 0.$$

For testing $H_0 : \theta = 1$ versus $H_1 : \theta = 4$, calculate the size and power of the test with rejection region $x < 2$.

5. Suppose X is a single observation from the density

$$f(x; \theta) = (\theta + 1)x^\theta, 0 < x < 1; \theta > -1.$$

- a) Prove that the most powerful size α test of $H_0 : \theta = \theta_0$ versus $H_1 : \theta = \theta_1 (> \theta_0)$, where θ_0 and θ_1 are specified constants, has rejection region $x \geq (1 - \alpha)^{\frac{1}{\theta_0 + 1}}$.
- b) Calculate the power of the above test.

6. $X_1, X_2, \dots, X_n$ is a random sample from a $N(1, \sigma^2)$ distribution. Derive the rejection region of the most powerful size α test of $H_0 : \sigma = \sigma_0$ versus $H_1 : \sigma = \sigma_1 (> \sigma_0)$. Find an expression for the power of the test.

Answers

1. (196.89, 222.61), (266.8, 1902.7).
2. 0.0668, 0.9332, $k = 3.47$, 0.2389
3. $5/32$, $1/2$
4. $1 - e^{-2}$, $1 - e^{-8}$
5. $1 - (1 - \alpha)^{\theta_1 + 1/\theta_0 + 1}$
6. $\Sigma(x_i - 1)^2 \geq \sigma_0^2 \chi_{n,\alpha}^2$, $P \left(\chi_n^2 > \left(\frac{\sigma_0}{\sigma_1} \right)^2 \chi_{n,\alpha}^2 \right)$.

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MATH2801 THEORY OF STATISTICS

Tutorial Problems - Week 13, 2003

1. Suppose X is a single observation from the density

$$f(x; \theta) = \theta e^{-\theta x}, \quad x > 0; \theta > 0.$$

- Prove that the most powerful size α test of $H_0 : \theta = \theta_0$ versus $H_1 : \theta = \theta_1 (< \theta_0)$ has rejection region $x \geq \frac{1}{\theta_0} \ln \frac{1}{\alpha}$.
 - Calculate the power of the above test.
 - Is the above test in any sense the best size α test of $H_0 : \theta = \theta_0$ versus $H_1 : \theta < \theta_0$?
 - Calculate the power function of the above test.
 - Is the test a size α test of $H_0 : \theta \geq \theta_0$ versus $H_1 : \theta < \theta_0$?
2. The article 'The Acute Effects of Chrysotile Asbestos Exposure on Lung Function' in the 1978 issue of Environmental Research reports the values of the pulmonary compliance (in $\text{cm}^3/\text{cm H}_2\text{O}$) for 16 persons 8 months after a prolonged period of exposure to asbestos (pulmonary compliance is a measure of lung elasticity). The sample mean and sample standard deviation were 209.75 and 24.156. Assuming a $N(\mu, \sigma^2)$ distribution for pulmonary compliance
- test at the 5% level the hypothesis $H_0 : \mu \geq 225$ versus $H_1 : \mu < 225$,
 - test at the 5% level the hypothesis $H_0 : \sigma^2 \leq 500$ versus $H_1 : \sigma^2 > 500$.
3. The article 'The Effect of Doping on the Voltage Holdoff Performance of Alumina Insulators in Vacuum' in IEEE Transactions, 1985, reported a random sample of 15 alumina ceramic insulators doped in a certain manner yielded a sample mean holdoff voltage (in kV) of 110 and sample standard deviation of 24. A sample of 76 plain alumina ceramic insulators gave a sample mean of 101 and sample standard deviation of 22. Assuming normality and common variance, carry out a statistical test of the hypothesis that the mean voltages for doped and plain insulators are the same.
4. Toxaphene is an insecticide which has been identified as a pollutant. To investigate the effect of toxaphene exposure on animals, a group of rats were given a dose of toxaphene in their diet. The article 'Reproduction Study of Toxaphene in the Rat' in the 1988 issue of the Journal of Environmental Science and Health reported weight gains (in grams) for rats given toxaphene and for control rats whose diet did not include the insecticide. The sample standard deviation of the weight gains for 25 control rats was 32 grams and for 21 exposed rats the sample standard deviation was 54 grams. Do these data suggest there is more variability in weight gain among exposed rats than among control rats?

Answers

- $\alpha^{\theta_1/\theta_0}$,
 - $p(\theta) = \alpha^{\theta/\theta_0}$.
- Observed $T = -2.525$, reject H_0
 - Observed $V = 12.85$, accept H_0 .
- Observed $T = 1.4$, accept.
- Observed $W = 0.35$, reject with a 5% level test.

teaching/2801/03/tutw13.tex